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ORBITING SATELLITE SURFACE TEMPERATURE PREDICTION AND ANALYSIS

USER'S MANUAL

Contract No. NAS9-1059

MRI Project No. 2669-E

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For

NASA - Manned Spacecraft Center
Houston, Texas 77001

MRI MIDWEST RESEARCH INSTITUTE

A PROGRAM TO DETERMINE SPACECRAFT HEAT LOADS AND TEMPERATURES....

MIDWEST RESEARCH INSTITUTE

ORBITING SATELLITE SURFACE TEMPERATURE PREDICTION AND ANALYSIS

by

H. L. Finch
D. Sommerville

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PREFACE

This User's Manual describes a computer program that was developed by Midwest Research Institute, Kansas City, Missouri, under Project No. 2669-E, for the National Aeronautics and Space Administration's Manned Spacecraft Center under Contract No. NAS9-1059. The User's Manual is a supplement to the Final Report, which describes the over-all project entitled, "Orbiting Satellite Surface Temperature Prediction and Analysis." The work was performed over the period from 4 February 1963 to 3 February 1964.

Mr. Harold L. Finch, Project Leader, developed the theory and worked on all phases of the program. Mr. Duncan Sommerville supervised the programming.

Mr. Roger Schroeder contributed to the selection of an applicable set of reference coordinate systems. Mr. Dean Lawrence performed the numerical analysis. Others who made significant technical contributions were Dr. Harry Sauer, Mr. Gary Sears, and Miss Rosemary Moran.

Approved for:

MIDWEST RESEARCH INSTITUTE

Harold L. Stout

Harold L. Stout, Director ep
Engineering Division

26 February 1964

bc

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SUMMARY

N64-22466

22466

The computer program described in this User's Manual was developed by Midwest Research Institute for the National Aeronautics and Space Administration's Manned Spacecraft Center. The purpose of the program is to determine impinging radiation heat loads and/or transient temperatures of vehicles[a] orbiting the moon, earth, or any other planet, except Pluto.

One of the unique features of the program is the ability to compensate for surface temperature gradients of the celestial body being orbited, thereby making the program especially applicable to project Apollo and other moon programs.

Spinning, planet-oriented, or sun-oriented vehicles can be evaluated. Up to 200 surface elements having various combinations of eight coatings and substrates can be analyzed in each case. Material thermophysical properties may be constant or temperature-dependent.

The initial project did not consider heat exchange between surface elements; however, the program can be expanded to be compatible with existing heat conduction programs. Programming has been done in FORTRAN to facilitate such modifications.

Hundreds of hypothetical test cases were run to check out specific routines and functions as well as the over-all program. The Lunar Excursion Module moon voyage, being planned for the late 1960's, was simulated on the computer. The results confirmed the importance of the program's ability to account for the moon's surface temperature gradients. This feature eliminated large errors in determining lunar thermal emission and resulted in improved vehicle temperature predictions, in one case by ±100°R. Simulated runs gave time-temperature curves that closely approximated the actual curves of the Explorer and Vanguard satellites.

Author

a/ The term "vehicle" is used to denote all manned and unmanned satellites, spacecraft, and other objects in orbit.

LIST OF SYMBOLS

a	- Semimajor axis of ellipse
b	- Semiminor axis of ellipse
C_p	- Specific heat
DEC	- Declination (latitude of sun w.r.t. X_c, Y_c, Z_c axes)
G	- Gravitational constant
h	- Thickness of vehicle skin
i	- Inclination of orbit plane
M_p	- Mass of planet
Q_g	- Internal heat generation
RA	- Right ascension (longitude of sun w.r.t. X_c, Y_c, Z_c axes)
r_p	- Radius of planet
T	- Temperature
T_p	- Average planet temperature
t	- Time
X,Y,Z	- Coordinate axes
α	- Angle between planet-sun line and X_p axis
β	- Angle between planet-sun line and Z_p axis
γ	- Angle between planet-sun line and Y_p axis
δ	- Angle between vehicle-sun line and vehicle-vehicle element line
ϵ	- Angle between vehicle element-vehicle line and vehicle-planet line
ϵ_v	- Emissivity of vehicle material

θ_s - Angle between sun-planet line and plane-vehicle line

Λ' - Angle between X_v axis and projection of vehicle-vehicle element line on X_v , Y_v plane

ρ - Density

$\sum$ - Angle between X_p axis and projection of sun-planet line on X_p , Y_p plane

ϕ - True anomaly

$\Delta\phi$ - The increment of ϕ between points where external heat fluxes are computed

ϕ_{in} - Value of ϕ where vehicle passes into the planet's shadow

ϕ_{out} - Value of ϕ where vehicle passes out of the planet's shadow

ϕ_c - Angle between vehicle-planet-sun plane and vehicle element-vehicle-planet plane

Ω - Longitude of ascending node

Ω' - Angle between Z_v axis and vehicle-vehicle element line

ω - Argument of perifocus

Subscripts

c - Celestial

e - Emitting body

o - Initial condition

p - Planet

r - Receiving body

s - Sun

v - Vehicle

I. INTRODUCTION

Thermal radiation and temperature play an important role in the development of spacecraft and their components. A computer program to predict these variables continuously as a vehicle[a] orbits a celestial body has been developed by Midwest Research Institute (MRI) for the National Aeronautics and Space Administration's Manned Spacecraft Center (NASA MSC). This program will assist thermal and structural engineers in analyzing actual and hypothetical spacecraft and missions.

A survey of the literature was conducted before initiating work on this project. The search revealed that existing methods were either too simplified, too specialized, or did not fulfill unique NASA MSC requirements.

One important criterion not included in previous approaches is the consideration of the effects of planet[b] surface temperature gradients on spacecraft heating. Surface temperature variations of cloud-covered planets are relatively small and unpredictable, thus their neglect in analyses of earth satellites is acceptable. On the other hand, temperature gradients on some planets are large and should not be neglected. The program developed under this contract is to be applicable to Project Apollo; therefore, it incorporates theory that accounts for the extreme surface temperature variations of the moon, as well as other nonuniformly radiating bodies.

While none of the available methods could be used "off the shelf," it was deemed that one of these, an Air Force computer program,[c] could be revised and expanded to fulfill NASA MSC requirements. MRI was contracted in February 1963 to develop the theory and to perform the necessary modifications to the existing Air Force program.

The over-all objective of the project was to develop an operable IBM 7094 FORTRAN program to determine impinging solar, planetary, and albedo[d] heat

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a/ The term vehicle is used to denote all manned and unmanned satellites, spacecraft, and other objects in orbit.

b/ The term planet in this report refers to the celestial body being orbited, whether it be the moon, the earth, or another planet.

c/ The Air Force program[1] was directed by Mr. Harold L. Finch, who is now a staff member of Midwest Research Institute and is Project Leader of the program described in this report.

d/ Albedo is considered in this report to be solar heat that is reflected from a planet and its atmosphere.

fluxes and/or temperatures of spinning vehicles or of a large number of infinitesimal surface elements of a vehicle that is planet- or sun-oriented.[a] Internal conduction is neglected in this initial study. While the program is capable of analyzing orbits about all planets except Pluto, special emphasis has been placed on problems associated with lunar missions.

The transition from the existing Air Force program to a program that meets the above objectives was accomplished by performing the following steps:

1. The existing program was checked out and inoperable routines were debugged on the 7094 computer.

2. The slow orbit-shadow intersection routine was replaced by an improved numerical method.

3. The program was reorganized into a pilot routine and a number of basic subroutines to facilitate debugging, recompiling, and program modifications.

4. A theory to account for planet surface temperature extremes was developed and programmed.

5. The program was expanded to include planet and sun-oriented vehicles.

6. The program was written to analyze up to 200 specific points on oriented vehicles. The points are assumed to be thermally insulated from the surrounding surface.

7. The input routine was made to accept standard NASA decks of temperature-dependent material properties.[b]

8. The program was developed to analyze internal heat as a function of time. Up to ten duty cycles per orbit are allowed. Different elements may have different internal heating cycles.

9. Standard data (e.g., astronomical planet data) were incorporated into the program body to facilitate preparation of input data.

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a/ An object is planet-oriented if the line connecting the vehicle and planet centers passes through the same vehicle surface element for all positions in the orbit path. Similarly an object is sun-oriented if the vehicle-sun line passes through the same surface element at all times.

b/ Standard NASA decks are decks of material properties developed by the Thermal Analysis Section of NASA MSC.

10. The input routine was written so that parametric studies can be made with a minimum amount of data preparation in successive cases.

11. Output options of printing temperatures and/or impinging heats were provided.

12. Numerous minor improvements were incorporated into the program.

13. Check cases to test the program logic and theory were devised and run.

Section II of this User's Manual contains instructions for preparing a deck and for assembling the components (monitor cards, data, object deck, etc.) in the proper sequence prior to submitting a run. Section III describes a method of estimating computer running time and lines of output and gives other information that will be useful to the operator. Section IV illustrates preparation of a data deck for a run consisting of three typical cases.

Appendix A describes the program - its organization and subroutines. Appendix B is a guide that is helpful in preparing data cards. Planet data incorporated into the program are summarized in Appendix C. Sample calculations for using an ephemeris to determine RA and DEC for an orbit about the earth, a planet, and the moon are contained in Appendix D.

The User's Manual describes only the use of the program; theory, additional illustrations, and more detail are included in the Final Report.

II. DECK SETUP AND DATA PREPARATION

In order to run the computer program, the user must prepare a deck having the following structure:

System control cards

Date card
I.D. card
XEQ card

Binary object program cards

Permanent data cards

General comment cards (optional)

Material properties cards

Material tables count card
Emissivity tables
First density table
First specific heat table
Second density table
Second specific heat table

.
.
.

Last density table
Last specific heat table

Case data cards

Case 1 comment cards (optional)
Case 1 data cards
Blank card
Case 2 comment cards (optional)
Case 2 data cards
Blank card

.
.
.

Last case comment cards (optional)
Last case data cards
Blank card

System control card

7-8 card (end of file)

The system control cards are standard for the FORTRAN II system. The binary object program cards and permanent data cards are furnished and will not normally need any changes. General comments are optional.

The recommended way of handling the material properties cards is to set them up on a permanent basis using emissivity tables for the eight most frequently used coatings or surfaces and density and specific heat tables for the eight most frequently used substrate materials. If this is done the user will be able to run a significant per cent of his jobs without having to alter this portion of the deck. Of course, if materials which are not among those chosen for the permanent tables are to be used, the material properties deck must be modified accordingly. However, the combined cases of a single job are limited to the materials read in at the beginning of the job.

Any number of cases may be run in a given job. Data for each case must be followed by a blank card. The job will terminate when the 7-8 card (end of file) is read.

Detailed information describing permanent data, comment, material, and case data cards is given below.

A. Permanent Data Cards

The program deck contains 148 "permanent" data cards which must always be present when running the program. These include a monitor DATA card, 144 cards containing the radiation configuration factors, and three cards containing alphabetic data used in headings. Since a monitor DATA card is part of the permanent data, no monitor DATA card should be added with the input data deck.

B. Comment Cards

Comment cards are used to identify and clarify the program output. They must have a number greater than nine in the first two columns, but the remaining columns may contain any Hollerith characters. Only columns 3-80 are printed as output. All comment cards are optional.

There are two kinds of comments, general comments and comments for specific cases. General comments must follow immediately after the permanent data cards. These comments are printed after a caption page and appear only once for a given computer job. General comments would normally be limited to information applicable to the job as a whole, while comments of a more specific nature would be placed ahead of the data for the pertinent cases. These specific case comments are printed as part of the case heading.

C. Material Properties Cards

Following the permanent data and general comments (if any) are the tables of temperature-dependent material properties. A count card precedes these tables which indicates how many tables of each property will be read in. Emissivity tables are required for each coating material used and for any substrate materials that are used without a coating. Specific heat and density tables are required for each substrate material.

Column two of the material tables count card gives the number of emissivity tables, and column four gives the number of substrate materials, for which a specific heat table and a density table will be read in.

Following the count card are all the emissivity tables. Next are specific heat and density tables alternately, one of each for every substrate material. This completes the tables of material properties.

Each table consists of temperature values in degrees Rankine alternating with values of the tabulated property and each terminates with the value following a temperature of 10000°R. Tabulation at 10000°R is necessary since the program extends the table until it reads this cut-off temperature. Units of specific heat are B/lb °R, and units of density are lb/ft^3.

The tables should be punched according to the FORTRAN format (6E12.8) and each table can have no more than seven cards. This format agrees with that of the standard thermal properties decks set up by the Thermal Analysis Section of NASA MSC. The last eight columns of each card may contain a code indicating material, property and card sequence number in the table. This code is included when the program lists the tables as part of its output.

Tables are numbered by the program in the order in which they are read in. A substrate property table need not have the same number as the emissivity table for the same material, as is shown in Case 1 of the sample data deck in Section IV.

D. Case Data Cards

The remainder of the data deck is made up of the following types of cards, which are differentiated by the card code number appearing in columns 1 and 2:

Card Code	Type of Card
Greater than 09	Comment
01	Case number and output control
02	Print control and angular interval
03	Planet and orbit
04	Element description
05	Sun position
06	Internal heat
07	Element count
Blank	"Start" card - signals end of case input

Comment cards, if any, must come first. The cards of type 01 through 07 are next and may be in any order.[a/] Finally, a blank card separates data of one case from that of the next and signals to the program that computation is to begin. It is important that no comment card be placed after the first non-comment card of each case, since this will result in termination of the entire job by the FORTRAN Monitor.

Numbers punched in the first ten columns of the card are read as integers[b/] and must be right justified in the specified field. Use no decimal point for these numbers.

All angles are to be read in degrees, all lengths in feet, temperatures in degrees Rankine, times in minutes and heat fluxes in B/ft^2-hr.

If a particular type of card is missing from the data for a given case, corresponding values from the previous case will be used. Therefore, one data card and one blank may be sufficient data for any case except the first.

Information that must be punched on cards with codes of 01-07 is discussed below for each type of card individually and is summarized in Appendix B.

1. Case number and output control (01 card): Columns 4-8 contain the case number, which must be an integer less than 32768. If heat fluxes only are to be printed out, column 10 must be blank or contain a zero. If temperatures only are to be printed out, column 10 must contain a 1. If both heat fluxes and temperatures are required, a 2 should be punched in column 10.

2. Print control and angular interval (02 card): Columns 11-18 contain ϕ_o , the vehicle position at time zero; columns 19-26 contain $\Delta\phi$, and columns 27-34 contain the number of revolutions or fractions thereof which the vehicle is to make around the planet. If columns 3-4 contain blanks, zero or 1, the program will write output at $\Delta\phi$ intervals. If columns 3-4 contain a number larger than 1, this number will indicate how many steps of size $\Delta\phi$ are taken between points where output is provided. Finally, unless columns

a/ An exception is the internal heat table continuation card. Details are found in the remarks on internal heat (06) cards.

b/ This format does not apply to the internal heat table (06) continuation card.

6-8 contain 359, the output will be in the normal columnar[a] form. If 359 is punched in columns 6-8, block[a] output will be used. In general, block output is useful only when the number of surface elements to be analyzed is very large, or in some cases if temperatures only are to be printed.

The basic angular interval, $\Delta\phi$, should be a submultiple of 360. For example: 5, 6, 7.5, 8, 9 and 10 are suitable values, but 7 is not, since 360/7 is not an integer.

Care should be given to the choice of $\Delta\phi$ since it represents the separation between points where the external heat fluxes are computed. Heat fluxes are assumed constant over the interval unless a sun-shade point lies within it.

3. Planet and orbit (03 card): Column 4 contains the planet code, which automatically carries with it corresponding constants shown in Appendix C for distance from sun, planet radius, albedo, GM_p, and cold side planet temperature. Codes for the planets in the program table are:

Earth - 1

Moon - 2

Jupiter - 3

Mars - 4

Mercury - 5

Neptune - 6

Saturn - 7

Uranus - 8

Venus - 9

---

a/ With columnar format, separate columns are used for temperature and each of the heat fluxes printed. At each printout point there is a row of output for each element being analyzed. With block output, separate blocks are used for temperature and heat fluxes. In each block the output values for all elements to be analyzed are printed, with 10 values on each line.

Orientation of the vehicle is indicated by a code punched in columns 5-6. The code is zero or blank if the vehicle is spinning, 1 if it is planet-oriented and -1 if it is sun-oriented. If the planet temperature is to be considered variable, column 8 must contain 1; a zero or blank indicates that planet temperature is constant. The orbit semimajor axis, a, and semiminor axis, b, are punched in columns 51-65 and 66-80, respectively. If fictitious orbits are used for test purposes, the values of a and b should satisfy the inequality

$$b^2 > r_p \, (2a-r_p)$$

where r_p is the planet radius from Appendix C. Otherwise, the orbit will intersect the planet.

4. Element description (04 card): Columns 4-6 contain the number of the element described; it may take on values from 1 to 200. Column 8 contains the number of the emissivity table pertaining to the element described; it may take on values from 1 to 8. Column 9 contains the number of the substrate material, and column 10 the number of the internal heat load table pertaining to the element described; these numbers may take on values from 1 to 8. Columns 11-18 contain Λ' for the element, and 19-26 contain Ω'. T_o is in 27-34 and h is in 35-42.

If an 04 card with a given element number contains blanks in place of any of the other information on the card, the program behaves as though the information deleted were copied from the last previously read 04 card having the same element number. If no such card was read previously, the information is taken as zero. Zero values should not be allowed for skin thickness, h.

5. Sun position (05 card): The 05 card may be used in two ways. If the sun's position is to be read in terms of angles α, β, and γ, 3 must be punched in column 4. Then α will appear in columns 11-18, β in 19-26 and γ in 27-34. If the sun's position is taken from an ephemeris, a blank or any number other than 3 in column 4 will cause the numbers i, ω, Ω, RA, and DEC to be read from columns 11-18, 19-26, 27-34, 35-42, and 43-50, respectively. The points ϕ_{in} and ϕ_{out}, where the vehicle passes in and out of the planet shadow, are normally computed from orbit geometry and sun position. However, they can be read in directly if 1 is punched in column 6 of the 05 card. In this case columns 51-65 should contain ϕ_{in} and 66-80 should contain ϕ_{out}. This feature was provided principally as a debugging aid, but could conceivably be used in other ways.

6. Internal heat (06 card): An undefined heat table is assumed to contain no heat loads. When a particular heat table is once defined, it remains unchanged until another 06 card redefines it. The first card of an internal heat table must have the number of the table punched in column 4; this number must be from 1 to 8. To redefine a heat table so that it has no heat loads, blanks or zeros are punched in columns 5-6. If nonzero heat loads are to be read in, columns 5-6 should give the number of internal heat values contained in the table aside from the value at time zero. This number may be from 1 to 19. The value of the heat load at time zero is punched in columns 11-18. The time when the first change occurs is in 19-26. The value after the first change is in 27-34. Second switching time and new heat load are in columns 35-42 and 43-50, respectively, and columns 51-65 and 66-80 represent third switching time and heat load after this time.

If the number in columns 5-6 is less than or equal to 3, a single 06 card is sufficient to describe one complete heat load sequence. In this case no 06 continuation cards are needed. However, if columns 5-6 contain a number from 4 to 19, then from 1 to 4 continuation cards are necessary.

Continuation cards must follow immediately after the 06 card which they complete. Each continuation card may contain as many as 8 values: 4 switching times and 4 corresponding new heat loads. The first switching time on each continuation card is punched in columns 3-10, and must be punched with a decimal point. This is the only exception to the rule that decimal points must not be used in the first 10 columns. Heat loads after switching are punched following the corresponding switching times until all the heat loads have been punched which were specified in columns 5-6 of the first 06 card of the table. The fields used include columns 3-10, 11-18, 19-26, 27-34, 35-42, 43-50, 51-65 and 66-80. An example of 06 continuation cards is given in Case 2 of the sample data deck, Section IV.

If the head load is constant at some value other than zero, an artifice must be used to enter the table properly. For, if a zero were left in column 6 to indicate that there were no changes in the heat load, the program would assume the heat load value to be zero. Therefore 1 must be punched in column 6. Then columns 11-18 should contain the constant heat load and 19-26 should contain a very large number, e.g., 900000., corresponding to the time at which switching occurs.

If the table contains switching times which are greater than the orbital period, these are ignored, since the program resets the internal heat tables to time zero at the end of each orbit.

7. Element count (07 card): The number of spacecraft surface elements for which heat fluxes and/or temperatures are to be found is punched in columns 4-6. This number may take on values from 1 to 200.

III. OPERATING INSTRUCTIONS: TIMING AND OUTPUT ESTIMATES

The program must be run with the FORTRAN II system. No special tapes are needed since the three scratch tapes used (A4, B3, and ~~B4~~ 46) are normally already mounted for all FORTRAN jobs. No sense switches are used.

Running time varies greatly with the number and type of cases to be run. Until experience with the program enables the user to make more accurate estimates, the following suggestions are offered as a guide:

Running time: 0.5 min. per case for up to 10 elements and
0.5 min. per case for each additional 20 elements

In estimating the amount of output for a job, about 20 lines for each case should be included for the heading and identifying information. Additional output is estimated in one of two ways. If the normal columnar output option is selected, the number of elements used should be multiplied by the number of printouts per element. If the block output option is used, the number of lines printed at each printout point will be two, six or eight, respectively, for up to 10 elements, depending on whether temperatures only, heat fluxes only or both are printed out. Each 10 additional elements results in one, three or four more lines of output, respectively.

IV. A SAMPLE INPUT DATA DECK

Preparation of input data is illustrated for a computer run consisting of three cases. The sample problems are not necessarily realistic as they were conceived only to illustrate a maximum number of the program's many options and to demonstrate the input routine's versatility.

A. Problem Definition of Sample Cases

The sample problems are defined as follows:

Case 1 - Determine the heat fluxes and temperatures of a moon-oriented vehicle orbiting the moon. Four surface elements are to be analyzed. Output data are to be printed every 5° for one orbit. Further specifications are as follows:

Moon surface temperature - variable

Sun position - given in an ephemeris for 2 July 1963

$i = 10°$

$\omega = 130°$

$\Omega = 70°$

$a = 6230000$ ft.

$b = 6211900$ ft.

$\phi_o = 0°$

$\Delta\phi = 5°$

Element 1

$\Lambda' = 30°$, $\Omega' = 90°$

$T_o = 500°R$

$h = 0.01$ ft.

$Q_g = 0.$

Material - uncoated T-3 aluminum

Element 2 - same as Element 1 except:

$\Omega' = 180°$ (Λ' is undefined)

$h = 0.005$ ft.

Element 3 - same as Element 1 except:

$\Lambda' = 210°$, $\Omega' = 90°$

Element 4 - same as Element 1 except:

$\Omega' = 0°$ (Λ' is undefined)

$h = 0.005$ ft.

Case 2 - Determine the temperatures of a spinning vehicle orbiting the earth. Output data are to be printed every 20° for 5.25 orbits unless the temperatures stabilize first. Two different internal heat loads are to be compared (this will be accomplished by running a single case using two "elements" which refer to different internal heat tables). Further specifications are:

Earth surface temperature - constant

Sun positions - specified in terms of α, β, and γ. Date not needed

$\alpha = 80°$

$\beta = 90°$

$\gamma = 170°$

$a = 22 \times 10^6$ ft.

$b = 22 \times 10^6$ ft.

$\phi_o = 280°$

$\Delta\phi = 4°$

Element 1

$T_o = 500°R$

$h = 0.01$ ft.

Q_g = 0 for 15 min., then 20 B/ft^2-hr for 15 min. This cycle continues throughout each orbit.

Material - uncoated T-3 aluminum

Element 2 - same as Element 1 except:

Q_g = 10 B/ft^2-hr continuously

Case 3 - Determine the temperatures of a sun-oriented vehicle orbiting the earth. Output data are to be printed in block form every 30° for one-half of an orbit. Four surface elements are to be analyzed. Further specifications are:

Earth surface temperature - constant

α , β , γ , a , b - same as in Case 2

$\phi_o = 190°$

$\Delta\phi = 2.5°$

Element 1

$\Lambda' = 0°$, $\Omega' = 90°$

$T_o = 500°R$

$h = 0.01$ ft.

$Q_g = 0$

Material - aluminum, painted black

Element 2 - same as Element 1 except:

Material - aluminum, painted white

Element 3 - same as Element 1 except:

$\Lambda' = 180°$

Element 4 - same as Element 1 except:

$\Lambda' = 180°$

Material - aluminum, painted white

B. Data Deck for Sample Cases

Data sheets representing the input cards for running the cases described above are illustrated in Fig. 1. Every card between the permanent data and the final 7-8 card (end of file) is shown. The values in the material properties tables should not be assumed valid since they are intended only to illustrate the required format. Each card on the data sheets has been given a sequence number in the left margin to aid in the discussion that follows.

1 - 3. These cards are seen to be comments because of the 10 in columns 1-2. Since they are read immediately following the permanent data, they are general comments and will be printed following the caption page and immediately preceding the tables of material properties. The third of the comments is blank in columns 3-80 and will result in a blank line in the output. Comment cards may be used in this manner to provide extra spaces in the output headings.

4. This is the first noncomment card following the permanent data and consequently it must be the material properties count card. It shows that six emissivity tables are to be read in followed by substrate tables for two materials.

5. Following the material properties count card is the first card of the first emissivity table. The last eight columns contain the code KEAL1. The user may punch any code he wishes in these columns to describe the table being read. This particular code refers to the emissivity table for aluminum.

The numbers in the first 72 columns describe the following table:

Temperature	Emissivity
0°R	0.055
9000°R	0.055
10000°R	0.3

The program interpolates linearly in this table to find emissivity for any given temperature. A table is complete when the emissivity corresponding to a temperature of 10000°R has been read. Hence the first table is complete on this card.

```
10MISCELLANEOUS COMPUTATIONS FOR SPACECRAFT IN ORBIT AROUND EARTH AND MOON
10 FEBRUARY 3, 1964
10
0602
0.          .055        9000.       .055        10000.      .3          KEAL1
0.          .970        10000.      .970                                EBP1
0.          .930        9000.       .93         10000.      .180        EWP1
0.          .36         9000.       .36         10000.      .49         EEX1
0.          .14         9000.       .14         10000.      .183        EVN1
+0          +00+22      +00+1       +05+22      +00                     ET31
0.          .22         10000.      .22                                 KCAL1
0.          172.8       10000.      172.8                               KRAL1
+0          +00+212     +00+56      +03+212     +00+66      +03+215     +00    CT31
+86         +03+228     +00+106     +04+24      +00+1       +05+24      +00    CT32
+0          +00+1728    +03+1       +05+1728    +03                     RT31
```

INPUT DATA SHEET

FOR

DETERMINING SPACECRAFT HEATING AND TRANSIENT TEMPERATURES

FORTRAN PROGRAM DEVELOPED BY MIDWEST RESEARCH INSTITUTE UNDER NASA MSC CONTRACT NO. NAS9-1059

1 2	3 4	5 6	7 8	9 10	11 18	19 26	27 34	35 42	43 50	51 65	66 80
10	CO	MP	UT	AT	ION OF H	EATS AND	TEMPERA	TURES FO	R FOUR E	LEMENTS ON THE	SURFACE OF AN
10	AL	UM	IN	UM	VEHICLE	ORBITIN	G THE MO	ON			
10											
01		5	01	02							
02					0.	5.	1.				
03	02	01	01							6230000.	6211900.
04		1	6	21	30.	90.	500.	.01			
04		4	6	21	0.	0.	500.	.005			
04		3	6	21	210.	90.	500.	.01			
04		2	6	21	0.	180.	500.	.005			
05					10.	130.	70.	55.29	-0.35		
07		4									
10	C	AS	E	TO	STUDY E	FFECT OF	SWITCHI	NG FREQU	ENCY OF	INTERNAL HEAT L	OADS
01		5	02	01							
02	05				280.	4.	5.25				
03	01									22000000.	22000000.
04		1		2							
04		2		3				.01			
05	03				80.	90.	170.				
06	02	8			0.	15.	20.	30.	0.	45.	20.
06	60.				0.	75.	20.	90.	0.	105.	20.
06	120.				0.						
06	03	1			10.	90000.	10.				
07		2									
02	12	3	59		190.	2.5	.5				
03	01	-1								22000000.	22000000.
04		1	2	11	0.						
04		2	3	11	0.	90.					
04		3	2	11	180.						
04		4	3	11	180.	90.		.01			
07		4									

Fig. 1 - Data for Sample Cases

The user has a choice of input formats for the material properties cards. This is discussed in detail in connection with cards 10 and 11.

6. The sixth card represents the emissivity table for black paint. Emissivity is shown to be constant at 0.970 for temperatures from 0° to 10000°R. This is the second emissivity table.

7. This card gives the third table, which is for white paint and shows emissivity to be constant at 0.93 for temperatures from 0° to 9000°R, but is 0.18 at 1000°R.

8 - 9. Cards 8 and 9 represent the emissivity table for a material which is not needed in Cases 1, 2 and 3.

10. The sixth emissivity table is shown on this card. The code refers to T-3 aluminum. This is the last of the six emissivity tables called for by the material properties count card.

This and the following card illustrate the two input formats which may be used in reading in the material properties tables. Both cards contain the numbers 0., 0.22, 1000. and 0.22. Card 10 has these numbers punched in the "exponential" format, which consists of a fraction less than 1. but not less than 0.1 and an exponent of 10 for determining the appropriate scale factor. No decimal point is used. On card 11 a decimal point is used, but no exponent need be punched. With the latter format the number may be punched anywhere in the designated 12-column field so long as a decimal point is used.

11. Substrate material property tables begin with this card. Each substrate material must have two tables, one for density, ρ , and one for specific heat, C_p . The code on card 11 shows that this is the C_p table for aluminum, which is designated substrate material 1.

12. The twelfth card contains the ρ table for substrate material 1. Cards 11 and 12 are both necessary to specify the first substrate material. It makes no difference, however, whether the ρ table or the C_p table is read in first since the program uses the product ρC_p and never uses either ρ or C_p alone.

13. Tables for substrate material 1 are complete, so this card describes substrate material 2. The code refers to C_p for T-3 aluminum. The 1 in the code indicates this is the first card of the table. Values of temperature and C_p from the card are:

T	C_p
0°	0.212
560°	0.212
660°	0.215

Since an entry for T of 10000° has not been punched, the table will be continued on the next card.

14. This card has the same code as card 13 except for the final 2, which indicates second card of the table. Values for temperature and C_p are:

T	C_p
860°	0.228
1060°	0.240
10000°	0.240

Since this card includes an entry for T of 10000°, the table is complete.

15. Card 15 gives the density table for substrate material 2. Six emissivity tables have now been read as well as specific heat and density tables for two substrate materials in accordance with the count given on card 4.

16 - 18. This card refers to Case 1. The three cards with 10 in columns 1-2 are comments. The third of these serves merely to provide an extra space in the output.

19. The 01 card gives the case number, 501. The 2 in column 10 indicates that both temperatures and heat fluxes are to be printed out.

20. The 02 card has $\phi_0 = 0$, and $\Delta\phi = 5$. The number 1 indicates one full orbit must be computed. The absence of any punch in columns 3-4 means that output is desired at each $\Delta\phi$ interval, and since columns 6-8 do not contain 359, the normal columnar output format will be used.

21. The 03 card has a planet code of 2 in column 4. This is the code for the moon. The 1 in column 6 indicates that the vehicle is moon-oriented and the 1 in column 8 means that the moon temperature is variable. The last two data are a and b .

22. The first 04 card describes element 1 since a 1 is punched in columns 4-6. Columns 8, 9 and 10 indicate that this element has emissivity given from emissivity table 6, density and specific heat from the tables for

substrate material 2 and internal heat from the first table of internal heat loads. The code for emissivity table 6 is ET3 (card 10). For substrate material 2 the codes are CT3 (cards 13-14) and RT3 (card 15). The element so described is of uncoated T-3 aluminum. Since there are no cards to define internal heat table 1, it is regarded as having no heat loads in it. The values of Λ' , Ω' , initial temperature, and thickness for the element are given as 30., 90., 500., and .01, respectively.

23. The second 04 card describes element 4 since a 4 is punched in columns 4-6. This element is similar to element 1 except for the values of Λ' , Ω' and thickness. The fact that the element 4 card is out of normal sequence is immaterial.

24 - 25. The next two 04 cards describe elements 3 and 2, respectively.

26. Since the 05 card does not have a 3 in columns 3-4, the sun position relative to the orbit is given in terms of i , ω , Ω , RA and DEC . These variables are punched as 10., 130., 70., 55.29, and -0.35, respectively. The determination of the indicated values of RA and DEC for 2 July 1963, is described in Appendix D. The absence of a 1 in column 6 indicates that the computer will find the sun-shade points, ϕ_{in} and ϕ_{out} . Any numbers punched in columns 51-80 are to be ignored. If a 1 had been punched in column 6, ϕ_{in} and ϕ_{out} would have been read from columns 51-80 of this card.

27. The 07 card carries a 4 in columns 4-6 meaning that four elements are to be analyzed for this case.

28. This blank card means that the data necessary for Case 1 is complete. When the blank is read processing of this example will begin. It was not necessary to include any 06 cards in the data for Case 1 since there are no internal heat loads.

29. The 10 card is a comment card pertaining to Case 2.

30. The 01 card has case number 502 in columns 6-8. The 1 in column 10 indicates that temperatures only are to be printed out.

31. The 02 card contains the data $\phi_o = 280.$, $\Delta\phi = 4.$, and the number of orbits = 5.25. The 5 in columns 3-4 indicates that output is printed only after every fifth interval, $\Delta\phi$. Hence output is at 20° intervals as desired. Normal columnar output is used since there is no 359 in columns 6-8.

32. The planet earth is designated by the 1 in column 4 of the 03 card. Blanks in columns 3-4 and 5-6 indicate that the vehicle is spinning and that the planet temperature is constant. Both a and b are 22000000.

33. The 1 in columns 4-6 of the 04 card indicates this is the data card for element 1. The 2 in column 10 indicates that Q_g is described in internal heat table 2. Since the remaining fields are blank corresponding data from Case 1 is used.[a/] Therefore, these blanks represent uncoated T-3 aluminum, $\Lambda' = 30°.$, $\Omega' = 90.$, $T_o = 500.$, and $h = .01$. Actually Λ' and Ω' are irrelevant since the vehicle is spinning.

34. Similarly the next 04 card describes element 2 as made of uncoated T-3 aluminum with $\Lambda' = 0.$, $\Omega' = 180.$, and $T_o = 500.$ Thickness must be read in as .01 since element 2 formerly had a thickness of .005. The 3 in column 10 means that internal heat table 3 contains the heat loads for this element.

35. The presence of a 3 in column 4 of the 05 card indicates that sun position relative to the orbit is given in terms of angles α , β , and γ . These are shown on the same card to be 80., 90., and 170. Since column 6 is blank, ϕ_{in} and ϕ_{out} are to be found by the computer and are not to be read in.

36. Next is an 06 card. The 2 in column 4 indicates that the second internal heat table is being described. The 8 in column 6 means that the table will contain an original heat load and a sequence of 8 changes. The initial heat load is shown in columns 11-18 as 0. This is valid until time t1 , which is shown to be 15 min. in columns 19-26. At this time the heat load becomes 20 B/hr-ft^2. This load is shown in columns 27-34. Similarly the heat load is switched again at 30 min. becoming zero and at 45 min. becoming 20 B/ft^2-hr.

37 - 38. Inasmuch as 8 changes are to be entered in internal heat table 2 and only 3 are shown on the first 06 card, continuation cards are required. On the first continuation the heat load is switched four times. At times of 60 and 90 min., it becomes zero, and at 75 and 105 min., it becomes 20 B/ft^2-hr again. On the second continuation card the heat load is switched for the eighth time. At 120 min. it becomes zero. Since the last heat load in the table is zero, this value is considered to extend on indefinitely. However, at the end of an orbit, the table will be reset, so that the cycle of

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a/ A blank field causes previously read values to be carried forward only in the case of 04 cards.

heat loads will be repeated at corresponding positions of successive orbits. The period for the orbit described in Case 2 is less than 120 min. so that the table will be reset before reaching the end. If a later case specifies an orbit of period greater than 120 min. without redefining this heat load table, the internal heat would be zero from 120 min. until the end of the orbit.

39. The next 06 card illustrates how a steady nonzero heat load may be specified. Column 4 shows that the third heat load table is being read. The initial value of the load is 10 B/ft^2-hr, and column 6 indicates that this is switched only once. The time when switching occurs is set at 90000 min. or two months. This should be much later than the end of any practical orbit and should cause the heat load to remain at 10. As a further precaution, the value after switching is given as 10 again. A zero or blank in column 6 cannot be used to indicate a steady nonzero heat flux since this code causes the table to be cleared of all heat loads.

40. The 07 card shows that two elements are to be processed.

41. The blank signals the end of input for Case 2.

42. Case 3 begins without any comments. From the 02 card: ϕ_o = 190. , $\Delta\phi$ = 2.5 and the number of orbits = 0.5. The program will, therefore, begin at $\phi = 190°$, proceed to 360° and then go on from 0° to 10° whereupon the case is terminated. Because of the 359 in columns 6-8, output will be in block form. The 12 in columns 3-4 means that the interval between points where output is written is 12 x 2.5° or 30°.

43. The 03 card has the planet code 1, for earth, punched in column 4. The -1 in columns 5-6 signifies that the vehicle is to be sun-oriented and the blank in column 6 indicates that planet temperature is constant. Orbit dimensions a and b are 22000000.

44. The 04 card describes element 1 since there is a 1 in column 6. Coating material 2 (black paint) is specified in column 8 and substrate material 1 (aluminum) in column 9. The 1 in column 10 means that the first internal heat load table applies. No 06 card has been included for this table; therefore, element 1 will have no internal heat loads. Values of 90., 500., and 0.01 for Ω' , T_o and h are carried over from card 22 of Case 1, while Λ' is punched at 0 .

45. Element 2 is specified by this card to be the same as element 1 except that coating material 3 (white paint) is indicated in column 8. It is necessary to punch a 90. for Ω' since this quantity was last specified on card 25 to be 180.

46. This card redefines the coating material (column 8), substrate material (column 9), internal heat load table (column 10) and Λ' (columns 11-18) for element 3 (column 6). Values carried over from card 24 are $\Omega' = 0.$, $T_o = 500°R$ and $h = 0.01$.

47. With this card, all data describing element 4 are changed except T_o , which would normally be punched in columns 27-34. The new description of element 4 coincides with that of element 3 except that the element 4 is coated with white paint rather than black.

48. The number of elements to be processed is entered in columns 4-6 of the 07 card.

49. Finally a blank signals the end of data for Case 3. Since no 01 card was included for Case 3, the case number, 502, will be repeated. Temperatures only will be printed as prescribed by card 30 of Case 2. Also no 05 card was included for Case 3. This means that α , β , and γ are carried over from Case 2, card 35.

APPENDIX A

ORGANIZATION OF THE PROGRAM

The program is written in the FORTRAN II language. It consists of a main routine and a number of subroutine and function subprograms. A number of FORTRAN library routines are also used such as square root, sine, arctangent, input, output, etc. No deck for any of the FORTRAN library routines is supplied with the program deck, but they are loaded by the system monitor at execution time from the library tape.

A simplified flow chart is given in Fig. A-1 to aid the user in following the program. The interrelationship between the main routine and all the subroutines is shown in Fig. A-2. A brief description of the main routine, subroutines, and functions is given in Sections 1 and 2. The source program contains numerous comments that may also help the user if he should desire to follow the program in greater detail.

1. Main routine and subroutines: PILOT is the main routine for the program. Its function is simply to define necessary constants and call the two major subroutines, TINPUT and LOOP. On exit from LOOP, the program returns to TINPUT for the next case.

TINPUT controls all input to the program. It also controls the output of headings, comments and all information used to explain and define each case. Subroutine SIGBET is also called by TINPUT in order that the values of Σ, β, ϕ_{in} and ϕ_{out} will be available for printing with the case headings.

HEAD prints a caption page and calls FREAD to read in permanent data.

FREAD reads in permanent data such as configuration factor tables, physical constants for the moon and eight planets, alphabetical heading information and frequently used constants. It also prints general comments and calls TABLE to read in material property tables.

TABLE reads tables of material properties and writes them on the output tape.

QIIN sets up new tables of internal heat loads whenever they are to be read in. Continuation cards are read until the table contains the specified number of entries. The table is also written on a scratch tape to be copied later on the output tape.

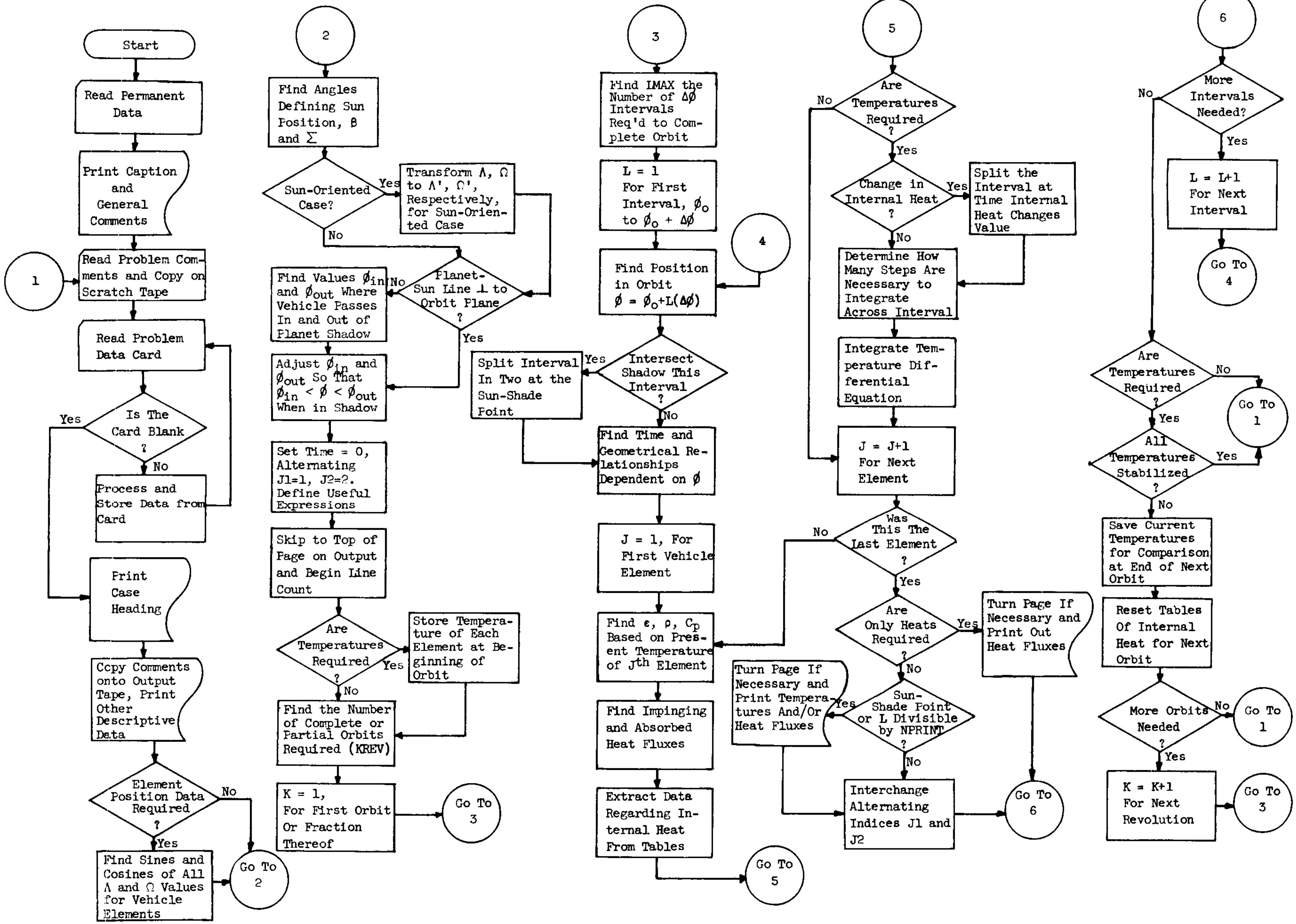

Fig. A-1 - Simplified Flow Chart

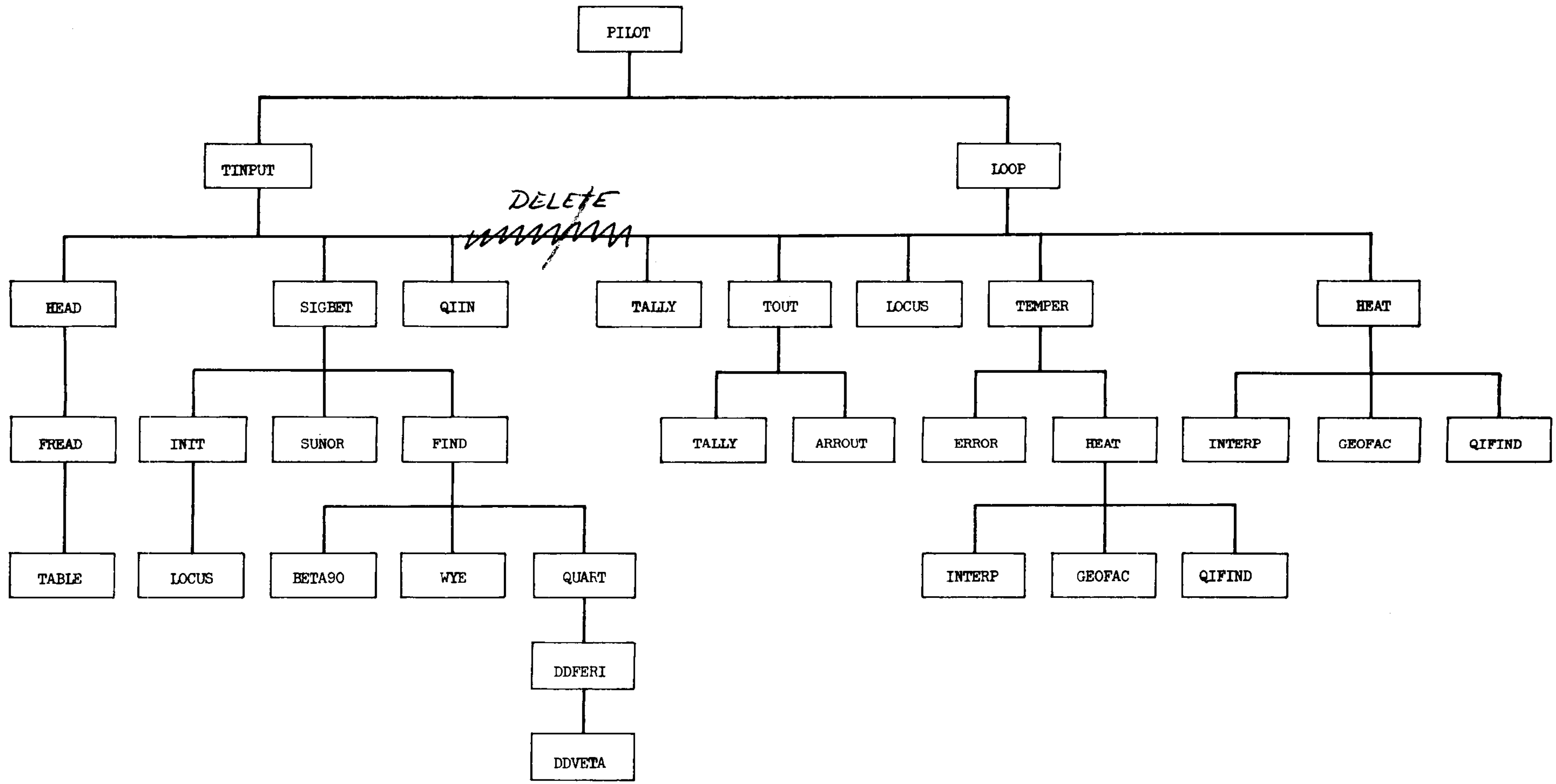

Fig. A-2 - Chart of Subroutine Hierarchy

SIGBET computes the angular position of the sun relative to the orbital plane. Two types of input data are accommodated: α , β , γ , or Ω , ω , i , RA , and DEC. This routine also calls FIND to locate the sun-shade points and SUNOR to transform element angles for the sun-oriented cases.

INIT adjusts the quadrants of ϕ_o , ϕ_{in} and ϕ_{out} so that $\phi_{in} < \phi < \phi_{out}$, whenever the vehicle is in the shade. This routine also determines whether the vehicle is initially in the sun or shade.

LOCUS calculates time, altitude and angle θ_s from ϕ , which represents the vehicle position. For oriented vehicles ϕ_c and δ are found. Angle ϵ is also found for sun-oriented cases. ϕ_c , θ_s and ϵ are arguments of the configuration factor tables, and δ is needed to determine solar heat flux. If T_p , the planet temperature, is variable, it is also found.

SUNOR converts the angular coordinates of the satellite elements from the input values to values acceptable to the program logic for sun-oriented satellites.

FIND locates the sun-shade points ϕ_{in} and ϕ_{out} . If the sun is in the orbital plane BETA90 is called. Otherwise QUART is called to determine the X_p coordinates and WYE to find the Y_p coordinates. Each point is checked to insure that it is not on the sunward side of the planet.

BETA90 computes the sun-shade points for cases where the sun is in the orbital plane.

WYE finds the Y_p coordinates of sun-shade points for which the X_p coordinates were calculated in QUART. Pairs of X_p and Y_p values are then checked to insure that they satisfy the equations of both the orbit ellipse and the shadow ellipse.

QUART solves for the roots of a quartic equation. The quartic arises when the equations for the orbit ellipse and the shadow ellipse are solved simultaneously for X_p .

DDFERI is a double precision quartic factorization program from the SHARE library.

DDVETA is a double precision cubic factorization program from the SHARE library. It is required by DDFERI.

LOOP causes a heading to be printed at the top of an output page and begins an output line count. Unless temperature calculations are not required, the maximum time interval is found for possible use in subroutine

ERROR. The initial temperature of each surface element is stored for comparison with the corresponding temperatures one full orbit later.

Next the program finds LINC, the number of intervals of width $\Delta\phi$ necessary to make one orbit and KREV, the number of complete or fractional orbits that will be required, provided that all temperatures do not stabilize earlier.

Then the vehicle is allowed to move counterclockwise around its orbit in steps $\Delta\phi$. For each step LOCUS is called to find time and other information depending on ϕ , and heat fluxes and temperatures are determined for each surface element. Output may be written after each interval $\Delta\phi$, or it may be deferred for two or more intervals under control of input parameter NPRINT.

If a sun-shade point is reached, output occurs automatically. If temperatures are being found, the integration of the differential equation over the interval is broken into two steps at the sun-shade point.

At the end of each complete orbit, temperatures are compared with corresponding temperatures one orbit earlier. If these agree to within 0.5°R, the case is considered finished. If not, the new temperatures are stored, the tables of internal heat loads are reset for a new orbit, and the program loops back unless the specified number of orbits read in has been exceeded.

TALLY counts lines of output aside from comments, headings and case identifying information. The printer carriage is restored when an output page is nearly filled.

TOUT handles all output except for comments, headings and case identifying information. Output includes ϕ , time and either heat fluxes or temperatures or both. With the normal option,data are printed in columnar format. However, an option to allow output to be printed in block form is also provided.

ARROUT is an auxiliary subroutine for output of arrays of data in block form.

TEMPER calls HEAT to obtain net heat flux into each vehicle surface element and the internal heat load. Then the differential equation for temperature is integrated over a given interval, $\Delta\phi$, of the orbit. If the interval is too long, or if internal heat loads are discontinuous within the interval, the interval is subdivided into two or more smaller steps.

ERROR computes a theoretical approximation to the truncation error resulting from the numerical integration. This routine is normally suppressed.

HEAT finds impinging heat fluxes for a specified satellite surface element. In cases where temperature calculations are required, absorbed heat fluxes are also found and QIFIND is called to determine the internal heat load.

INTERP finds values of emissivity, density or specific heat for a specified temperature by means of linear interpolation in material property tables.

GEOFAC interpolates in tables of configuration factors to find a value corresponding to given ε , ϕ_c , θ_s and altitude. For values of these parameters outside the range of tabulated entries, the program extrapolates. This feature is useful for θ greater than 90°. However, if the factor found results in a negative heat flux, subroutine HEAT will replace it by zero.

QIFIND determines whether the internal heat for the surface element in question is varied during the interval of integration. If so, it provides initial and final heat loads and the time at which switching occurs.

2. Functions: ARCOS finds the arccosine in degrees of the argument. ARCOS is always from zero to 180 inclusive.

PHIFN is the ratio $\Delta T:\Delta t$ of temperature change to time increment as calculated from the numerical integration algorithm.

FOFXY is the derivative of temperature with respect to time for a given temperature and location in orbit.

DELTA is an auxiliary function used by ERROR.

GFN is an auxiliary function used by ERROR.

APPENDIX B

A GUIDE FOR PREPARING DATA CARDS

Columns	Right Justify in Field	Use Decimal Point	
			01 Cards - Case Number and Output Control
4-8	X		Case number - must be less than 32768.
10			A code to determine whether heat fluxes or temperatures or both are to be printed out. Blank or zero signifies heats only; 1 is temperatures only; 2 is both.
			02 Cards - Print Control and Angular Interval
3-4	X		A code number, NPRINT, to control printing. Blanks or a 1 cause printout after each interval $\Delta\phi$; otherwise program prints only after NPRINT intervals.
6-8	X		A code to control output format. Block output is used only if these columns contain 359. Columnar output is used in all other cases.
11-18		X	ϕ_o , the vehicle position at time zero.
19-26		X	$\Delta\phi$, the basic angular increment between points where heat fluxes and temperatures are computed.
27-34		X	The number of revolutions or fractions thereof that the vehicle is to make around the planet.

Columns	Right Justify in Field	Use Decimal Point	
			03 Cards - Planet and Orbit
4			Planet code - must be from 1 to 9. Codes and corresponding planets are: 1.Earth, 2.Moon, 3.Jupiter, 4.Mars, 5.Mercury, 6.Neptune, 7.Saturn, 8.Uranus, 9.Venus.
5-6	X		Blank or zero means vehicle is spinning; 1 means it is planet-oriented; -1 means it is sun-oriented.
8			Blank or zero means planet temperature is constant; 1 means it is variable.
51-65		X	a , the orbit semimajor axis.
66-80		X	b , the orbit semiminor axis.
			04 Cards - Element Description
4-6	X		The number used to identify the element being described - must be from 1 to 200.
8			The number of the emissivity table for the element being described - must be from 1 to 8.*[a]
9			The number of the substrate material tables for the element being described - must be from 1 to 8.*

a/ If an 04 card contains blanks in any data field marked with an asterisk, the program continues to use the value from the previous case for the element in question. Absence of an 04 card for a given element causes all values from the previous case to be carried forward.

Columns	Right Justify in Field	Use Decimal Point	
			04 Cards (Concluded)
10			The number of the internal heat load table for the element being described - must be from 1 to 8.*a/
11-18		X	Angle Λ' for the element being described.*
19-26		X	Angle Ω' for the element being described.*
27-34		X	T_o , the initial temperature, for the element being described.*
35-42		X	h , the skin thickness, for the element being described.*
			05 Cards - Sun Position
3-4	X		A code to signal what type of data is used to describe sun position. If this is a 3, then α, β, γ are read; if it is not 3, then i, ω, Ω and ephemeris data are read.
6			Blank or zero indicates program is to compute sun-shade points ϕ_{in} and ϕ_{out}; 1 means they are to be read in.
11-18		X	i , the angle of inclination, unless column 4 contains a 3, in which case it is angle α.
19-26		X	ω , the argument of perifocus, unless column 4 contains a 3, in which case it is angle β.
27-34		X	Ω , longitude of the ascending node, unless column 4 contains a 3, in which case it is angle γ.
35-42		X	RA, right ascension, unless column 4 contains a 3, in which case it is ignored.
43-50		X	DEC, declination, unless column 4 contains a 3, in which case it is ignored.

a/ See Footnote a/ on p. 33.

Columns	Right Justify in Field	Use Decimal Point	
			05 Cards (Concluded)
51-65		X	ϕ_{in} , the point where the vehicle enters the planet's shadow. The program ignores this number unless a 1 is punched in column 6.
66-80		X	ϕ_{out} , the point where the vehicle leaves the planet's shadow. The program ignores this number unless a 1 is punched in column 6.
			06 Cards - Internal Heat (first card of table)
4			The number of the internal heat table which is being read in - must be from 1 to 8.
5-6	X		If greater than zero this is the number of heat values other than the starting value to be read into this table. If blank or zero, it signals that the table has no heat loads.
11-18		X	$Q_g(0)$, the initial heat load, for the table indicated in column 4.
19-26		X	t_1 , time at which the first change of heat load in this table will occur.
27-34		X	$Q_g(t_1)$, heat load value from time t_1 .
35-42		X	t_2 , time at which the second change of heat load in this table will occur.
43-50		X	$Q_g(t_2)$, heat load value from time t_2 .
51-65		X	t_3 , time at which the third change of heat load in this table will occur.
66-80		X	$Q_g(t_3)$, heat load value from time t_3 .

Columns	Right Justify in Field	Use Decimal Point	
			k^{th} 06 Continuation Card - Internal Heat (k=1,2,3,4)
3-10		X	t_{4k} , time at which the $4k^{th}$ change of heat load in table will occur.
11-18		X	$Q_g(t_{4k})$, heat load value from time t_{4k} .
19-26		X	t_{4k+1} , time at which the 4k+1 change of heat load in this table will occur.
27-34		X	$Q_g(t_{4k+1})$, heat load value from time t_{4k+1} .
35-42		X	t_{4k+2} , time at which the 4k+2 change of heat load in this table will occur.
43-50		X	$Q_g(t_{4k+2})$, heat load value from time t_{4k+2} .
51-65		X	t_{4k+3} , time at which the 4k+3 change of heat load in this table will occur.
66-80		X	$Q_g(t_{4k+3})$, heat load value from time t_{4k+3} .
			07 Cards - Element Count
4-6	X		The number of spacecraft surface elements for which temperatures and/or heat fluxes are to be found.

APPENDIX C

PLANET DATA USED BY THE PROGRAM[a]

Planet Code	Planet	Distance from Sun (ft)	Radius (ft)	Albedo	GM_p (ft^3/sec^2)	Cold Side Temp. b/ (°R) Adjusted	Actual
1	Earth	48.89×10^{10}	20.9×10^{6}	.39	$141. \times 10^{14}$	200	450[4]
2	Moon	48.89×10^{10}	5.702×10^{6}	.053	1.73×10^{14}	186	186[5]
3	Jupiter	255.3×10^{10}	229.3×10^{6}	.51	$44900. \times 10^{14}$	50	219[2]
4	Mars	74.81×10^{10}	10.87×10^{6}	.148	15.20×10^{14}	200	365[6]
5	Mercury	19.03×10^{10}	8.151×10^{6}	.058	7.66×10^{14}	10	10[6]
6	Neptune	$1475. \times 10^{10}$	81.51×10^{6}	.62	$2435. \times 10^{14}$	50	60[2]
7	Saturn	467.9×10^{10}	188.7×10^{6}	.50	$13450. \times 10^{14}$	50	130[2]
8	Uranus	941.3×10^{10}	83.6×10^{6}	.66	$2058. \times 10^{14}$	50	82[2]
9	Venus	35.43×10^{10}	20.34×10^{6}	.76	114.8×10^{14}	200	450[7]

6. Page 37 - Add the following footnote: b/ Cold side temperatures are utilized only by the variable temperature method, which was developed especially for celestial bodies that have a negligible atmosphere (eg. the moon). If this method is used for other bodies, the predicted temperature gradients will be too large due to neglect of conduction and convection by the atmosphere. The program makes some compensation by employing "adjusted" cold side temperatures.

a/ "Distance from Sun" and moon's mass data from Fowle.[2] Radius, mass and albedo data from Ehricke,[3] except the moon's albedo specified by NASA Project Engineer.

APPENDIX D

THE SUN'S POSITION - SAMPLE CALCULATIONS

The position of the sun can be expressed, with respect to the planet coordinate axes X_p , Y_p , Z_p in terms of α , β , and γ as shown in Fig. 7 of the Final Report. These data can either be read in directly as input data or they can be calculated by the program from five input variables, Ω , ω , i , RA and DEC.

The angles RA and DEC, which are illustrated in Fig. 6 of the Final Report, can be obtained from an ephemerides for each day of the year. Sample calculations for earth, a planet (Mars), and the moon are illustrated below for 2 July 1963 using the American Ephemeris and Nautical Almanac.

For earth, RA and DEC are determined from apparent right ascension and apparent declination data. These data are tabulated at the top of Fig. D-1 in hours, minutes, and seconds where 24 hours is equivalent to 360°.

Accordingly,

$$\text{RA} = \frac{\text{6 hr. 40 min. 58.88 sec.}}{24} \times 360 \approx 100.2^\circ$$

and

$$\text{DEC} \approx \frac{23.1^{\circ}\text{ hr. 06 min. 31.8 sec.}}{24} \times 360 \approx 346.0^\circ$$

For a planet other than earth, longitude and latitude data are used. The data for Mars given in the middle of Fig. D-1 are converted as follows:

$$\text{RA} = 200^\circ 20' 43.5'' + 180^\circ \approx 380^\circ 21' \approx 20^\circ 21'$$

$$\text{DEC} = -(+0^\circ 53' 42.5'') \approx -0^\circ 54'$$

SUN, 1963

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FOR 0^h EPHEMERIS TIME

Date		Apparent Right Ascension		Apparent Declination		Radius Vector		Semi-diameter	Equation of Time Apparent – Mean	
		h m s	s	° ′ ″	″			′ ″	m s	s
July	1	6 36 50·66	248·22	+23 10 22·5	−230·7	1·016 6915	+121	15 45·40	− 3 32·12	−11·66
	2	6 40 58·88	[illegible]	23 06 31·8	255·0	·016 7036	79	15 45·39	3 43·78	11·40
	3	[illegible]	247·66	[illegible]	279·1	·016 7115	39	15 45·38	3 55·18	11·10
	4	6 49 14·49	247·35	22 57 37·7		·016 7154	+			
	5			22 52						

MARS, 1963

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HELIOCENTRIC POSITIONS FOR 0^h EPHEMERIS TIME
MEAN EQUINOX AND ECLIPTIC OF DATE

Date		Julian Date	Longitude	Latitude	Radius Vector	Orbital Longitude	Daily Motion	Orb. Lat.
		243	° ′ ″	° ′ ″		°	°	″
July	2	8212·5	200 20 43·5	+0 53 42·5	1·617 224	200·33278	0·463 189	+0·02
	6	8216·5	202 12 06·9	0 50 32·0	·613 476	202·18981	·465 342	·01
	10	8220·5	204 04 01·7	0 47 17·3	·609 611	204·05563	·467 579	+ ·01
	14	8224·5	205 56 29·1	0 43 58·7	·605 635	205·930[illegible]	·469 896	·00
								− ·01

MOON, 1963

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EPHEMERIS FOR PHYSICAL OBSERVATIONS

FOR 0^h UNIVERSAL TIME

Date		Age	The Earth's Selenographic				Physical Libration			The Sun's Selenographic		Position Angle of				Fraction Illuminated
			Longitude		Latitude		Lg.	Lt.	P.A.	Colong.	Lat.	Axis		Bright Limb		
		d	°	°	°	°	(0°01)			°	°	°	°	°	°	
July	1	9.5	+1.28	−1.26	−6.71	+0.42	0	−4	−1	22.50	0.36	19.57	−3.19	292.1	−1.8	0.70
	2	10.5	+0.02	1.22	6.29	0.69	0	4	−1	34.71	0.35	16.38	3.91	290.3	2.6	0.78
	3	11.5	−1.20	1.12	5.60	0.95	0	4	0	[illegible]	0.32	12.47	4.56	287.7	3.3	0.86
	4	12.5	2.32	0.97	4.65	1.16	0	4	0	59.12	0.30	7.91		284.4	3.7	0.92
	5			0.80	3.49	1.35	0	4	0	71.32	0.27					

Fig. D-1 - Ephemeris Data Required for RA and DEC Sample Calculations

For the moon, colongitude and latitude are used. The data at the bottom of Fig. D-1 are transformed as follows:

$$RA = 90^\circ\text{-colongitude} \approx 90^\circ-34.71^\circ \approx 55^\circ 29'$$

$$DEC = \text{latitude} \approx -0.35^\circ$$

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